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FIBER OPTIC SONOBUOY CABLE DEVELOPMENT FY76

Electro-optical components for data transfer between deep submerged acoustic sensors and surface buoys

RA Eastley

8 August 1977

Prepared for
NAVAL AIR DEVELOPMENT CENTER
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The following personnel at NOSC were the major contributors to this development: GA Wilkins, cable design and mechanical test; WH Putnam, fiber development and contract monitoring; DH Stephens, link development and environmental tests; and J Redfern, link analysis.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document provides a summary of fiber optic sonobuoy development through FY76. Optical fibers were incorporated into developmental sonobuoy cables with attenuations as low as 4.8 dB/km at 0.85 µm* and 1.8 dB/km at 1.05 µm*. A 0.5-dB/km attenuation increase was observed at a hydrostatic pressure of 48 MPa (7 kpsi). Less than 1-dB/km attenuation increase was observed for tension and bending stresses. Discussions of cable development; optical, mechanical, and environmental cable tests; fiber and link studies; and measurement techniques are presented. It is recommended that observed deficiencies be reduced to operationally acceptable levels through continued fiber optic sonobuoy cable development.

* micrometers

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OBJECTIVE

Develop fiber optic sonobuoy cables and associated electro-optical components for data transfer between deep submerged acoustic sensors and surface buoys.

RESULTS

1. The cable manufactured by ITT/Electro-Optical Products Division was the best of the three cables developed and tested. Optical fiber attenuations as low as 4.8 dB/km at 0.85 μm were measured. Certain deficiencies were noted: attenuation increased 0.5 dB/km at 48 MPa (7 kpsi) hydrostatic pressure, less than 1 dB/km in the 0 to 30°C temperature range, and up to 10 dB/km for tension and bending stresses.

2. A link analysis indicated that 5 km (16 500 ft) depths are feasible using available 10-dB/km optical fibers with relatively inexpensive light-emitting diodes and silicon PIN photodiodes.

3. A study of the water integrity of optical fibers (maintenance of fiber strength and optical properties in the undersea environment) revealed serious deficiencies in the strength of EVA-buffered Corning Glass Works (CGW) optical fibers. CGW projected the initial strength of 1-km-length fibers to be 0.5 GPa (75 kpsi), whereas the sonobuoy cable requires fibers 5 km in length having a fatigued strength of 1.4 to 2 GPa (200–300 kpsi).

4. A contract at The Catholic University of America pursued the goals of developing a potentially low-cost optical fiber manufacturing technique. The goal of the contract was to fabricate a 300-metre, 20-dB/km, 0.3-NA graded-index fiber. The best produced was a 30-metre, 37-dB/km, 0.23-NA step-index fiber.

RECOMMENDATIONS

1. Reduce observed cable deficiencies through continued fiber optic cable development.

2. Develop electro-optical components for incorporation into laboratory and field test links.

3. Improve the strength and operational life of long-length optical fibers.

4. Defer exploratory development of the Catholic University process until ongoing research indicates lower risk in fabricating low-cost optical fibers for sonobuoys.

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INTRODUCTION

Optical fiber attenuation and strength have been improved to the point where optical fibers now appear to be candidates for the signal transfer medium in 5- to 7-km sonobuoy cables. Fiber attenuations as low as 4–5 dB/km are now being achieved in production and an experimental fiber has been produced with 0.5-dB/km attenuation.[1] Production 1-km-length fibers have proof-tested strengths of 0.7 GPa (100 kpsi) and experimental 2-km fibers are being pulled having proof-tested strengths of 2.4 GPa (350 kpsi).[2] A typical 5-km sonobuoy cable system requires an operational attenuation of less than 10 dB/km and operational fiber strengths of 1.4 to 2 GPa (200–300 kpsi).

Optical fibers are worthy competitors to electrical wire systems for a number of reasons. The bandwidth of 10-km optical fibers is quite significant: at least 4 Mbps for step index fibers and 200 Mbps for graded index fibers. The optical fiber, which is non-conductive by nature, does not exhibit the impedance change, which is a function of the amount of wire left on the reel, or the signal loss caused by pinholes in cable insulation, that the electrical wire exhibits in a sea-return link. The optical fiber, which is small (0.125 mm) and lightweight, has the potential of being available at low cost, $0.01 per metre in large-quantity buys.

An early milestone in the development of optical fiber systems at NOSC was a 3-km step index unbuffered fiber having a 3-dB/km attenuation at 0.82 μm wavelength. This achievement indicated that long fibers might be incorporated in long sonobuoy cables with low cabled fiber attenuation, less than 10 dB/km. Since that achievement, efforts have been initiated in (1) fabrication of fiber optic sonobuoy cables; (2) investigation of a low-cost fiber process at Catholic University; (3) investigation of the water integrity (maintenance of fiber strength and optical properties in the undersea environment) characteristics of fibers at Corning Glass Works; (4) analysis of a fiber optic sonobuoy link signal transfer; (5) development of laboratory and field test instrumentation for the measurement of attenuation, dispersion, and numerical aperture; and (6) optical, mechanical, pressure, temperature, bend, and tension tests on fabricated optical cables.

FIBER OPTIC CABLE FABRICATION

The fiber optic cable fabrication task consisted of 300-m to 1-km length prototype cable fabrication at ITT, Roanoke, VA; US Polymerics, Anaheim, CA; Simplex Wire and Cable Co, Portsmouth, NH; and Air Logistics Corp, Pasadena, CA.

The objective of this effort was to produce strong cables [at least 800N (180 lb)] containing one or two optical fibers with a cable diameter of 1.45 mm (0.058 inch), a cabled fiber attenuation of 10 dB/km or lower, a bandwidth of 100 kbps, and a bend radius of 2.5 cm. Cables produced at US Polymerics and Air Logistics were designed by NOSC; ITT and Simplex cables were produced under NOSC contract.

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[1] Horiguchi, M, and H Osanai, Spectral Losses of Low-OH-Content Optical Fibers, Electron Lett 12, 553, 1976

[2] Maklad, M, High Strength Optical Fibers, presented at the High Strength Optical Fiber Workshop, La Jolla, CA, 6 July 1976

ITT CABLE

The attenuation of the two ITT-manufactured step index fibers in the cable (fig 1) prior to cabling was 5.6 dB/km at 0.85 μm and 2.8 dB/km at 1.05 μm. The fiber attenuation after cabling is 4.8 dB/km at 0.85 μm and 1.8 dB/km at 1.05 μm for one of the fibers and 3.7 dB/km for the other.[3]

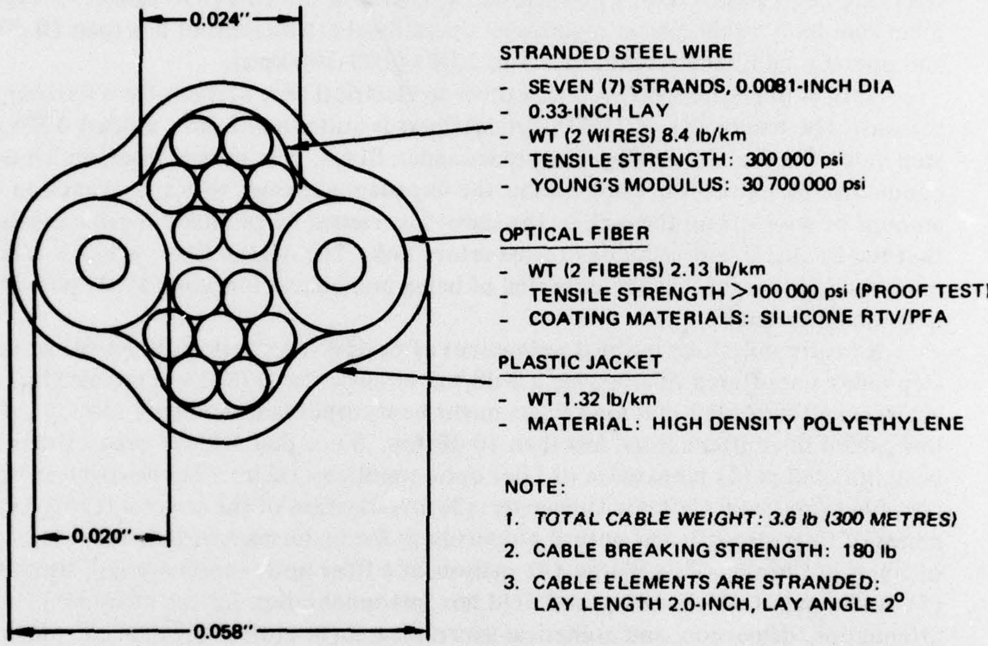

Figure 1. ITT fiber optic sonobuoy cable.

Figure 2 indicates the fiber strength improvement obtained during the course of the contract. The cable was produced under contract number N00123-75-C-1023.

AIR LOGISTICS CABLE

The attenuation of the step index fiber in the Air Logistics cable (fig 3) was 7.3 dB/km prior to cabling and 7.8 dB/km at 0.82 μm after cabling. The fiber was manufactured by ITT. The cable was produced under contract number N66001-75-C-0045.

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[3]ITT Electro-Optical Products Division, 300 Metre Sonobuoy Cable; 500 Metre Tow Cable, by RJ Freiburger, 15 July 1976

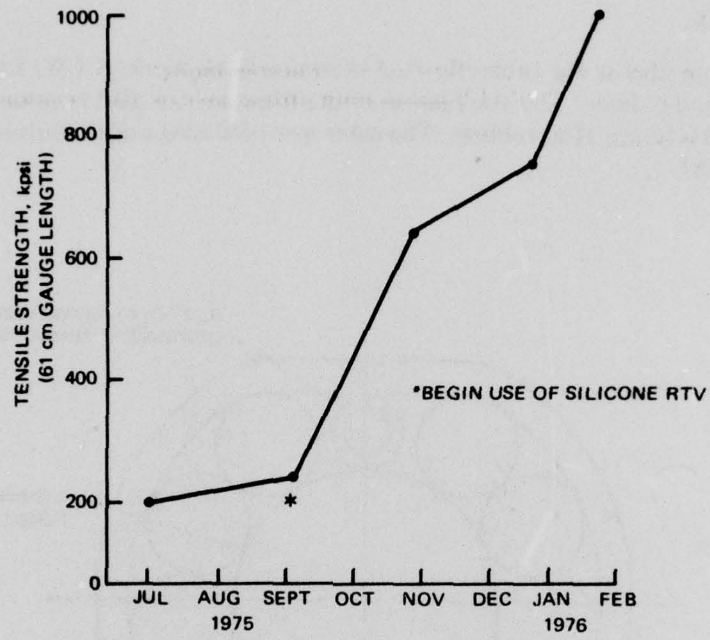
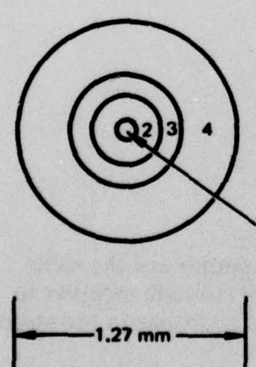


Figure 2. ITT fiber strength improvement.



NOSC/AIRLOG CABLE UNIT

1. 0.125-mm-DIAMETER, STEP INDEX OPTICAL FIBER (ITT #SCVD 259).
2. TEFLON (PFA) BUFFER, ADDED BY ITT TO 0.38-mm DIAMETER.
3. LOW-SHORE, LOW-MODULUS ELASTOMER #240-1, ADDED BY AIR LOGISTICS TO 0.64-mm-DIAMETER.
4. LOADBEARING STRUCTURE, ADDED BY AIR LOGISTICS TO FINAL DIAMETER OF 1.27 mm. THIS STRUCTURE CONTAINS 9840 PARAXIAL, HTS-901 S-GLASS FILAMENTS IN A POLYAMIDE-MODIFIED, AMINE-CURED, EPOXY RESIN SYSTEM (AIR LOGISTICS #380-4). THE S-GLASS VOLUME FRACTION IN THE MATRIX IS APPROXIMATELY 0.64.

Figure 3. Air Logistics fiber optic sonobuoy cable.

SIMPLEX CABLE

The optical fiber in the cable (fig 4) is a Corning Glass Works (CGW) Kynar/EVA-buffered graded-index fiber. The attenuation of the fiber was 6.1 dB/km prior to cabling and 24 dB/km at 0.82 μm after cabling. The cable was produced under contract number N00123-76-C-0251.

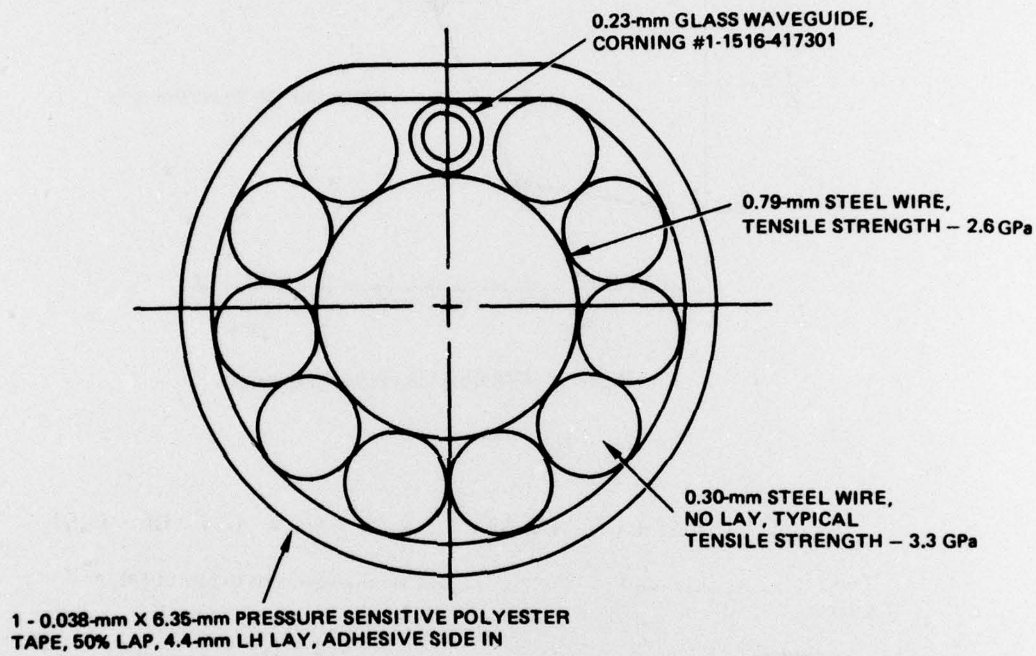


Figure 4. Simplex fiber optic sonobuoy cable.

US POLYMERICS CABLE

The Polymerics cable (fig 5) approach was dropped after samples of the cable exhibited an unacceptable tendency of the impregnated Kevlar-49 strength member to kink. In addition, the fibers could not be held in their designated positions in the structure during manufacture.

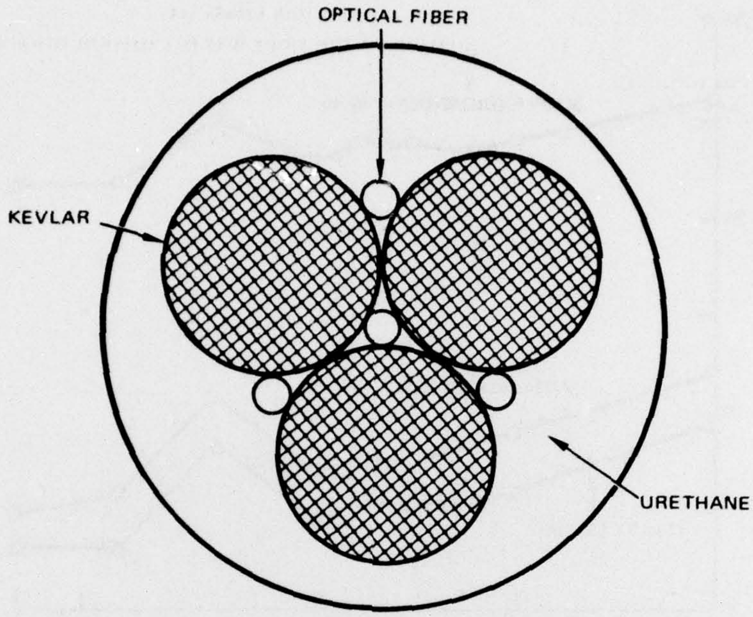


Figure 5. US Polymerics fiber optic sonobuoy cable.

OPTICAL, MECHANICAL, AND ENVIRONMENTAL CABLE TESTS

The manufactured cables were subjected to optical, environmental, and mechanical tests at NOSC.

OPTICAL TESTS

Spectral attenuations of the ITT, Simplex, and Air Logistics cables were measured[4]; the data are presented in figure 6. The 0.8 to 0.89-μm region of the spectrum has the lowest attenuation where EO sources and detectors are currently available.

MECHANICAL TESTS

The ITT and Air Logistics cables were tested[5] for tensile pull to failure, tensile cycling, and loaded flexure over 10-cm-diameter grooved sheaves. Optical continuity was monitored during the tests.

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[4]NELC TR 2006, Fiber Optic Tow Cable Optical and Environmental Tests, by WH Putnam, 20 December 1976

[5]NUC memorandum ser 653-8, Physical Test Results for NUC and NELC Fiber Optical Cable Units, by G Wilkins, 7 July 1977

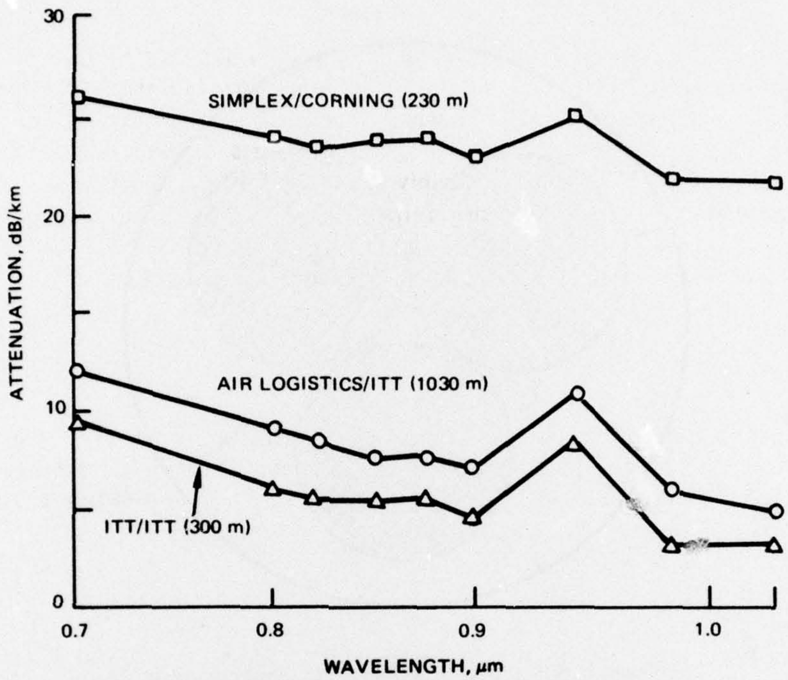

Figure 6. Cabled fiber spectral attenuation.

TENSILE TESTS

The ITT cable strength and elongation characteristics are compared to the Air Logistics cable in table 1.

TABLE 1. COMPARISON OF CABLE TENSILE PROPERTIES.

Strength, N (lb)	ITT	Air Logistics
Highest load at break	1228 (276)	257 (579)
Lowest load at break	1179 (265)	2451 (551
Mean load at break	1201 (270)	2504 (563)
Elongation, %		
Highest at break . . .	2.19	5.51
Lowest at break . . .	1.68	4.08
Mean at break . . .	1.93	4.58

TENSILE CYCLING

Neither cable unit showed any signs of degradation under tensile cycling.

FLEXURE UNDER LOAD

A 5-cm radius of curvature was chosen as a reasonable minimum radius for a generalized cable, and it also represents the threshold for rapid increase in optical fiber bending loss. Both cables performed extremely well when flexed at 20% of their short-term breaking load. The critical load threshold for the Air Logistics cable lies somewhere between 20% and 30% while that of the ITT cable is probably upwards of 40%. The ITT cable at 40% of ultimate load is actually under less tension than the Air Logistics cable at 20%. The Air Logistics cable is a ridged cable compared to the ITT cable. However, no degradation of the physical structures of either cable was noted at any load or flexure life.

ENVIRONMENTAL TESTS

Pressure, temperature, and tension can adversely affect the attenuation characteristics of a fiber optic sonobuoy cable.[6] The pressure associated with a 5-km depth is 50 MPa (7 kpsi). The operating temperature varies from -4°C to +30°C but storage temperature of -50°C to +70°C can be encountered. In addition, the cable must perform while coiled to a 2-cm bend radius in the sonobuoy cylindrical cable pack. The load placed on the 1.5-mm-diameter cables in operation is 311 N (70 lb), but is subjected to additional loading from cable weight and deceleration. All these factors can affect the fiber coating's ability to isolate the fiber from stress. The cables were tested against these specifications.

PRESSURE TESTS

The average attenuation increase for a 5-km depth is presented in table 2.

TABLE 2. AVERAGE ATTENUATION INCREASE FOR 5-km DEPTH.

	ITT	Air Logistics	Simplex
Flooded . . .	0	—	62
Nonflooded . . .	53	12.5	—

TEMPERATURE TESTS

The attenuation variation as a function of temperature is shown in table 3.

TABLE 3. ATTENUATION INCREASE (dB/km) AS A FUNCTION OF TEMPERATURE.

Temperature	ITT	Air Logistics	Simplex
+70°C	2	Deformed 63°C, broke	38 (decrease)
-50°C	6	5	54
Return to ambient	8	—	12

[6] NELC TN 3276, Fiber Optic Sonobuoy Cable Environmental Tests, by DH Stephens, 21 Dec 1976

TENSION

Direct pull and bending tension tests were conducted at NOSC. Optical attenuation measurements were made during these tests. During the pull test (table 4), the optical fiber in the ITT cable broke at 480 N (108 lb), which is 60% of the design strength of 800 N (180 lb). The test mandrel was 1.9 cm in diameter. The Air Logistics and Simplex cables have not been pull-tested.

TABLE 4. PULL TEST, ITT CABLE.

Tension, %	Force, N (lb)	Attenuation Increase, dB/km
0	0	0
20	160 (36)	0
40	320 (72)	1
60	480 (108)	10 (average over two readings)

The bend tests were made by reeling and unreeling the cable onto mandrels 16, 10, 5.7, and 3.8 cm in diameter. The results for the ITT cable are presented in table 5.

TABLE 5. ITT CABLE BENDING TEST.

Spindle Diameter, cm	Attenuation Increase or Decrease (–), dB/km
16	-1
10	0
5.7	5
4	10

The strength member of the Air Logistics cable failed when the bend radius was less than 1.9 cm (0.75 inch); the Simplex cable was permanently deformed when the radius was smaller than 1.25 cm (0.5 inch).

OPTICAL LINK

It was determined from a study of 5-km sonobuoy cable requirements[7] that two optical sources are available for use in the fiber optic link: the light-emitting diode (LED) and the laser diode. There are also two detectors available for the optical link: the avalanche photodiode (APD) and the PIN diode.

The laser diode has an output in the 10 mW (+10 dBm) range and a fiber coupling loss of 3 dB. The LED has an output of 2 mW (+3 dBm) and a fiber coupling loss of 16 dB. The required receiver level is about -75 dBm for the APD and -65 dBm for the PIN diode.

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[7]NUC TN 1654, Preliminary Analysis of the Requirements for a Fiber Optic Cable for Sonobuoy Applications, by J Redfern, March 1976

The laser diode is a better source than the LED, but it is presently more expensive. The APD is more sensitive than the PIN diode but it requires higher supply voltage and is more expensive. The maximum allowable fiber losses for the source and detector combinations are shown in table 6.

TABLE 6. MAXIMUM ALLOWABLE CABLE FIBER LOSS FOR SOURCE AND DETECTOR COMBINATIONS.

Source/Detector	Cable Loss, dB/km
Laser diode/APD	16
Laser diode/PIN	14
LED/APD	12
LED/PIN	10

Step index fibers are available with attenuation less than 4 dB/km; plastic-clad silica fibers are also a candidate. Fiber dispersion will not be a problem at the bandwidths anticipated over the 5-km length.

Present costs of optical fibers are $1.50 per metre. Large production estimates are predicted to be as low as $0.01 per metre by manufacturers.

The present sonobuoy electrical pulses will need to be modified to a type best suited for an optical source (fig 7).

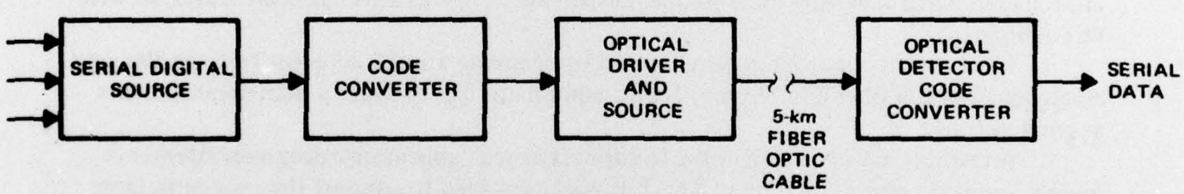

Figure 7. Optical data transmission.

The electrical data are converted to a biphase code format that drives the optical source; the detected optical pulses are converted to the desired serial data stream.

A proposed optical code is a series of narrow pulses showing biphase properties (fig 8). A pulse occurs at each clock boundary guaranteeing clock synchronization at the receiver while eliminating difficulties resulting from long sequences of "0." A data "1" is indicated at midpoint in the clock interval by a pulse, and a data "0" by no pulse. The average source duty cycle lies between 1 in 5 and 1 in 10. Receiver bandwidth of about 2 MHz is adequate to resolve the 1-μs-wide pulses. Following optical detection, the code may be converted to any other code desired. Alternate transmission code formats such as pulse position modulation or multilevel encoding are possible, but require greater wire system modification.

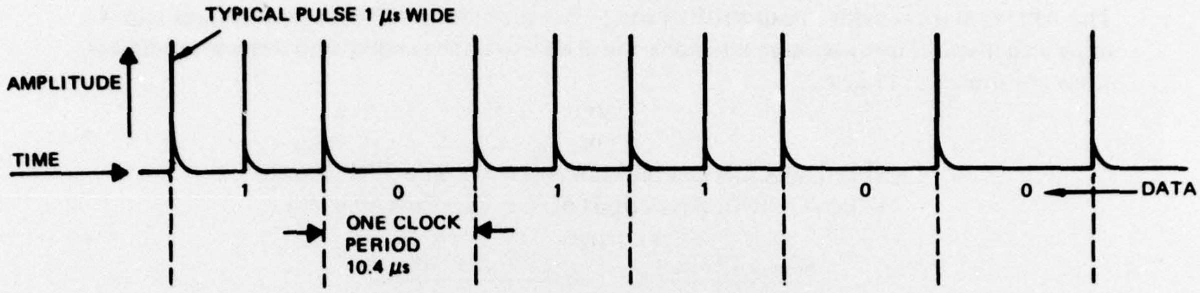

Figure 8. Optical code sequence.

EO MEASUREMENT CAPABILITY

NOSC has developed both laboratory and field test equipment for the measurement of optical fiber attenuation, dispersion, and numerical aperture.[4]

Attenuation measurements at selected wavelengths from 0.5 to 1.05 μm are made of buffered and cabled fibers having lengths from 50 m to 1 km. Accuracy of these measurements is 0.2 dB/length (km). Single-wavelength (0.82 to 0.85-μm) attenuation measurement equipment has been developed to support mechanical and environmental cable tests.

Fiber dispersion is measured by using a short pulsed laser diode, a silicon avalanche photodiode, and a sampling oscilloscope. Dispersion as low as 2 ns has been measured with this equipment.

Fiber numerical aperture is measured by scanning a small detector through the light emerging from the fiber end. Present NOSC equipment can measure a numerical aperture as great as 0.24.

A test hut has been assembled to support at-sea cable attenuation measurements during simulated operational tests. This hut was assembled to support the near-term large tow cable tests but is available for sonobuoy testing.

WATER INTEGRITY OF OPTICAL FIBERS

The purpose of the water integrity study was to study the strength, fatigue, and optical attenuation of low-loss coated optical fibers in various environments, both in the stressed and unstressed state.[8] The effect of the undersea environment (pressure, temperature, and humidity) on the strength and optical attenuation of plastic (ethylene vinyl acetate) coated optical fibers was examined by Corning Glass Works under NOSC contract.

Short-term fiber strength was measured before and after 500-hour exposure to a laboratory, 98% relative humidity (RH) and seawater environment. The sample size was 40 fibers, each fiber 60 cm long. No significant loss of strength was observed. Static fatigue experiments were conducted at 63% and 60% of the mean short-term strength in 98% RH, and at 55% of this strength immersed in seawater, for periods up to 500 hours. The fatigue rate was found to be independent of both the stress level and environments in these tests. A near coincidence of 100% failures was achieved after 500 hours at a stress level close to 60% of the mean short-term strength. The Weibull (empirical analytical method for statistical prediction) parameters m (shape) and δ(scale) were determined from short-term strength data and used to predict the strengths of 1-km-long fiber. Static fatigue data provided the value for fatigue rate, which was then used to predict fatigue strengths (0.5 GPa or 75 kpsi) of 1-km-long fiber.

[8]Corning Glass Works, Water Integrity of Optical Fibers, by ST Gulati et al, Nov 1975

The effect of temperature and pressure on the optical attenuation at $\lambda = 0.6328\ \mu m$ was also measured. In the temperature range -50°C to +20°C and 20°C to 75°C, the change in optical attenuation was approximately 2 dB/km, which is within the experimental uncertainty of measuring apparatus. The change in optical attenuation attributable to a hydrostatic pressure of 13.8 MPa (20 kpsi) was also negligible (0.3 dB/km).

The results of this preliminary study permit prediction of failure rates of these CGW fibers at various stress levels, gauge lengths, and exposure time to the above environments. Fiber strength and fatigue are strong functions of the manufacturing and coating process and must be evaluated with each process change. The fibers used in this study are representative of those used in the Simplex sonobuoy cable.

LOW-COST FIBER DEVELOPMENT

A potential low-loss fiber processing technique was investigated[9] at Catholic University (CU) under contract N00123-74-C-1411. The goals of the contract were to develop 5-dB/km fibers by a process called molecular stuffing developed at CU. Shortly after the contract was awarded, CU requested and was granted a goal of 20-dB/km deliverable fibers. CU was unable to deliver the optical fibers but presented the findings of their development in a final report.

It appears that the chemical vapor deposition (CVD) fiber produced by optical fiber manufacturers will be just as inexpensive as the CU fiber is calculated to be. In addition, the low-loss, long-length, high-strength fiber requirement for the sonobuoy application could easily cause the CU process to become complex and higher in cost.

The Phasil process developed at Catholic University can be described as follows. The base glass for a fiber optic preform is made from reagent grade materials and its subliquidus phase separation is used to purify it to the low transition metal ion impurity levels necessary to meet the needs of optical communication applications. Briefly, the purification of the glass by the Phasil process is as follows: Alkali-borosilicate glasses are melted from low-cost reagent grade materials and fabricated into rod preforms. The glass compositions are chosen to allow separation into phases of different chemical compositions. With suitable heat treatments, these phases are continuous within each other (highly interconnected). The ionic phase, which is less durable to attack by acid, is chemically leached and removed from the glass structure. The proper choice of initial composition allows the removal of all the alkali and most of the boron in this step. The concentration of transition metal impurity most detrimental to optical communication applications (iron) will divide between the two phases according to solubility (partition function). This partition favors the ionic phase so that most of the iron is removed by the leaching and subsequent washing steps. The glass is then in the form of a porous skeleton approximately 94% SiO_2. A molecular stuffing step is possible at this time whereby a wide variety of dopants may be added to the porous glass by means of an aqueous solution to change the physical properties of the base glass (ie, refractive index, thermal expansion, strength).

The remaining steps consist of drying the preform, oxidizing the iron remaining within the glass and consolidating the preform by collapsing the pores. Finally, a fiber is drawn from the preform with the desired index profile resulting from the molecular stuffing step and the necessary high purity (low iron concentration) resulting from the purification (phase separation) step.

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[9] Catholic University of America, Vitreous State Laboratory, Final Report of Contract N00123-74-C-1411, 26 Nov 1975

CONCLUSIONS

CABLE

1. Low-loss optical fibers can be incorporated into developmental sonobuoy cables with low attenuation after cabling. The ITT cable fiber attenuation was 4.8 dB/km at 0.85 μm; the Simplex cable (24 dB/km) failed to meet the 10-dB/km specification; the Air Logistics cable had a 7.8-dB/km attenuation.

2. Fiber optic cables should be able to be fabricated in long lengths (5 to 7 km or longer) since conventional cable manufacturing techniques were employed in producing the prototype cables.

3. ITT cable test results indicate that large attenuation increases (>50 dB/km) are experienced in cabled fibers subjected to 48 MPa (7 kpsi) unless the cable is permitted to flood. The attenuation increase was 0.5 dB/km for the flooded cable. Void-free cable design has not been investigated.

4. The ITT cable exhibited the best optical characteristics during the environmental tests. Attenuation increased 2 dB/km at 70°C; 6 dB/km at -50°C; 1 dB/km pulled at 40% of rated tension; and 10 dB/km at 60% of rated tension (fiber broke – mandrel bend radius 1.9 inches).

5. The tensile test results for the ITT cable were a mean load at break of 1201 N (270 lb), mean elongation at break of 1.93%; the Air Logistics cable had a strength mean of 2504 N (563 lb) and an elongation mean of 4.58%.

6. No degradation of the physical structures of either the Air Logistics or ITT cables was noted during tensile cycling and flexure under load.

LINK ANALYSIS

7. To use inexpensive LEDs and PIN diodes, a 5-km system would require operational cable attenuation not to exceed 10 dB/km. The ITT cable attenuation of 4.8 dB/km at 0.85 μm provides a margin of 5.2 dB/km for excess loss resulting from factors such as pressure, temperature, tension, and bend radius; the Air Logistics cable provides a 2.2-dB/km margin. The Simplex cable, 24 dB/km, is unusable with any available transmitter/receiver combination.

8. Available step index optical fibers will provide a data link without restriction imposed by the uncoiled cable.

9. Sources and detectors presently available are suitable for the optical link.

WATER INTEGRITY OF OPTICAL FIBERS

10. No significant loss of strength of CGW fibers was observed after 500-h exposure to laboratory, 98% RH, and seawater environments.Fiber fatigue rate was found to be independent of both stress level and environment in these tests. A near coincidence of 100% failures was achieved after 500 h at a stress level close to 60% of the mean short-term strength. The effect of pressure and temperature on EVA-buffered fiber attenuation was negligible, 0.3 dB/km at 0.6328 μm and 13.8 MPa (20 kpsi), and 2 dB/km from -50°C to 75°C, which was within experimental uncertainty of the measuring apparatus.

LOW-COST FIBER DEVELOPMENT

11. Catholic University could not deliver the low-loss fibers (5 to 20 dB/km) specified as deliverables in their molecular stuffing low-cost fiber development contract. Their estimate of funding needed to fulfill sonobuoy goals is as follows:

Task	Amount	Time (years)
Fiber Strength	$200k	2
Numerical Aperture	80k	2
Very Low Absorption (2 dB/km)	200k	3
Precision Profile Control	100k	1
Upscaling for Long Lengths (10 km)	200k	2

Recent high-volume cost projections by fiber manufacturers of the modified chemical vapor deposition process are comparable with those made by CU for their process. Economics combined with the complexity of the CU process and emerging dopant purity problems now make the CU approach unattractive.

RECOMMENDATIONS

1. Continue cable design, fabrication, and test and evaluation efforts to minimize attenuation increases from factors such as pressure, temperature, tension, and bending stresses. Continue investigation of buffer materials and thicknesses to alleviate stresses.

2. Determine precisely the expected sonobuoy cable stress conditions.

3. Develop winding and unwinding methods for optical cables.

4. Modify sources and detectors for incorporation into a sonobuoy link and conduct both laboratory and field functional tests.

5. Investigate duplex techniques, both spacial and single core, and integrate selected technique into sonobuoy fiber optic link.

6. Improve NOSC EO measurement equipment and techniques for better accuracy and stability.

7. Continue fiber strength improvement, through cable contracts and DARPA strength improvement contracts. The goal is 1.4–2 GPa (200–300 kpsi) for 7-km length depending on fatigue characteristics. NOSC will be testing the fibers produced to verify strength and recommend strength improvements.

8. Defer development of the Catholic University (CU) fiber process until their research indicates a risk level appropriate to exploratory development.

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